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BIENNIAL REPORT OF THE DIRECTOR OF LICK OBSERVATORY.[1]

(Period July 1, 1910, to July 1, 1912.)

MOUNT HAMILTON, July 1, 1912.

To the President of the University:

Sir: I have the honor to submit herewith my sixth biennial report, covering the period July 1, 1910, to July 1, 1912.

The financial difficulties connected with the publication of the more extensive investigations completed by members of our staff have been serious during the past six years, and many of them still exist.

The results secured by the D. O. Mills Expedition to the Southern Hemisphere during its first period, 1903-06, which were ready for publication in June, 1908, went to press late in 1910, thanks to a private gift from Mrs. HEARST for this purpose. The printing was completed and the publication was distributed to our correspondents late in 1911. A share of the expense, not covered by the gift, was defrayed by drawing upon the current maintenance funds of the observatory.

Abstract: The financial uncertainty and inability have likewise caused the printing of Volume VII, *Publications of the Lick Observatory,* containing contributions from the Berkeley Astronomical Department, to be distributed over a decade. This volume should be ready for mailing in January. The reproduction of Professor BARNARD'S photographs of the Milky Way and comets, obtained at Mount Hamilton prior to his resignation in 1895, have been partially completed by the means of funds contributed by California friends of Professor BARNARD and of the observatory. The cost of completing the

[1] Several paragraphs of the complete report have been omitted and others are presented in abstract.

volume must be met from other sources of funds. Likewise, it has been impossible to publish a proposed volume containing about one hundred reproductions of Halley's comet photographs secured by Dr. CURTIS and the spectrograms obtained by Mr. WRIGHT. Similarly, we have been unable to prepare a proposed eclipse volume to contain reproductions of the unique and extensive series of photographs secured by the seven expeditions sent out from Lick Observatory. Funds are wholly lacking to publish in moderate detail the stellar radial velocities secured at Mount Hamilton and at the D. O. Mills Observatory in the Southern Hemisphere. In order that the general results may be available, it was decided to publish the mean observed velocities for the individual stars as rapidly as possible in the Lick Observatory Bulletins. The velocities of the Class B and Class A stars and of the large proper-motion stars have been so published. The mean velocities of the Classes F, G, K, and M stars are ready for publication, in manuscript form. They will be issued within the next few months, practically as charges against the meager maintenance funds of the observatory. Early in the year 1913 the mean velocities of about fifteen hundred stars should be available to students of the stellar system.

Dr. AITKEN has the manuscript well advanced for a quarto volume to contain his observations and studies of the more interesting visual double stars which he has made during the past decade.

It is apparent from the foregoing paragraphs that serious efforts should be made to secure a satisfactory solution of our publication problems. As there have been several years, both before 1906 and since 1906, when absolutely no funds were available in the State Printing Office, it is hoped that the next Legislature will make a greatly increased appropriation, in order that the arrears of printing may be removed. . . .

The first holder of the Martin Kellogg Fellowship is Dr. KEIVIN BURNS, who served five years as Carnegie Institution Assistant in the Lick Observatory. Dr. BURNS has been engaged in study and research in Bonn University during the entire academic year 1911-12, and it is to the advantage of the researches which he is conducting that he remains at Bonn during the first semester of next year. His principal work has

consisted in determining with extreme accuracy the wave-lengths of the lines in the arc spectrum of iron. He has covered the entire region of spectrum from extreme red to ultra-violet available for photographic record. The positions of about four thousand iron lines have been determined to a degree of accuracy entirely satisfactory to Dr. BURNS and to Professor HEINRICH KAYSER, under whose direction the work has been conducted. . . .

The support of the D. O. Mills Observatory at Santiago, Chile, following the lamented death of Mr. MILLS, was generously assumed by his son, Mr. OGDEN MILLS. Funds to the amount of $15,000 were provided late in 1910 to cover the expenses of the work in the Southern Hemisphere during the years 1911 and 1912; and in February, 1912, Mr. MILLS made a further contribution of $15,000 to provide for the years 1913 and 1914. The publication of the results for the brighter stars for the years 1903 to 1906 have given rise to numerous expressions by astronomers concerning the fruitfulness, accuracy, and importance of the work at Santiago. The studies concerning the motion of the solar system through space and the structure of the stellar universe, which we have been able to make on the basis of observations secured at Monut Hamilton and at Santiago, have increased the demands for knowledge concerning the motions of fainter stars. This field of research has proved to be one of exceeding richness, and ten leading observatories in the Northern Hemisphere are devoting a large proportion of their resources to its cultivation. The D. O. Mills Observatory was the first to enter this field in the Southern Hemisphere, in 1903. A few years ago the Cape of Good Hope Observatory began to devote a share of its resources to the prosecution of similar researches. It is, of course, impossible that the two southern observatories should extend the work as rapidly as the ten institutions in the Northern Hemisphere, and it is a well-recognized fact that the northern results cannot assume their full strategic value, nor even approach their full strategic value, until they are balanced by similar observations in the southern sky. The deficit of southern results will be severely felt in a few years, and it is desirable that more powerful equipments join in studying the radial

velocities of southern stars. It is not an over-statement to say that astronomers everywhere are grateful to Mr. OGDEN MILLS for extending the life of the D. O. Mills Observatory. . . .

The library of the observatory is excellent in all departments closely related to the lines of research undertaken here, but in other departments, especially in that embracing the history of astronomy and in the sciences closely allied to astronomy, it could easily be better. It is my policy to improve it in every possible manner, but unfortunately not many dollars can be spared for this purpose from the funds for the general maintenance of the observatory. We are all anxiously looking forward to the time when the library may be added to and cared for by virtue of an annual fund of definite amount.

Astronomer TUCKER was away from Mount Hamilton during the period May 1, 1908, to October 15, 1911, on three years' leave of absence granted to afford him the opportunity of installing the meridian observatory of the Carnegie Institution of Washington, at San Luis, Argentina, and of superintending the work of that observatory, under the direction of Professor LEWIS Boss, who remained at Albany, New York. Mr. TUCKER and his staff of ten assistants set a pace which had never been approached in observations of this class, by securing 87,000 complete meridian observations of stellar positions in less than two years of actual observing, April, 1909, to January, 1911, inclusive. The months prior to the period described were devoted to the construction of the observatory and of the living quarters, and the months following the observational period were used in dismounting and returning the instruments to Albany, and in well-deserved vacation. While the subject is one in which the Lick Observatory has no responsibility, it is a satisfaction to record in passing that the observations secured by Mr. TUCKER and his staff will form a vital part in Professor Boss's great catalogue of extremely accurate stellar positions covering the entire sky.

During the years 1906-08 Mr. TUCKER had prosecuted energetically an observing program for fundamental determinations of star positions. The reductions of these observations were held in abeyance during his absence, and his duties during the

current academic year have related almost entirely to the preparation of the 1906-08 results for publication. . . .

It is well known that most meridian observers note the transits of brilliant stars across the lines of their instruments relatively earlier than the transits of faint stars. At intervals since 1896 Mr. TUCKER has secured extensive series of observations to evaluate his personal equation as affected by the brightness of the stars under observation. His equation has been remarkable for its constancy: bright stars have been observed relatively too early to the extent of 0.009 second of time per visual magnitude; that is, a first-magnitude star is observed too early with reference to a seventh-magnitude star by about 0.054 second of time.

Mr. TUCKER has recently observed a selected list of stars at the request of the superintendent of the United States Coast and Geodetic Survey.

The Lick Observatory double-star survey of the northern sky, which was originated in all its essential features by Dr. AITKEN in April, 1899, has continued to receive a large share of his attention. Professor HUSSEY had joined in the prosecution of the survey from July, 1899, to May, 1905. Our splendid summer weather enabled Dr. AITKEN to complete the survey for the northern summer sky nearly two years ago. Of the 20,625 square degrees in the Northern Hemisphere 19,225 square degrees have been completed, leaving incomplete about 1,400 square degrees, mainly between 6 hours and 10 hours of right ascension and in regions near the equator. Estimating the area from the equator to declination 22° south at 9,000 square degrees, we may say that 7,740 degrees have been completed, and 1,260 square degrees, mainly between 2 hours and 10 hours of right ascension, of which 1,100 degrees are south of declination — 14°, are still unobserved. Except for Dr. AITKEN's ill health in the winter of 1910-11 and for the uncommonly poor winter and spring of 1911-12, the survey should now be essentially complete. In the progress of the survey Professor Hussey discovered about 1,300 double-star systems and Dr. AITKEN about 2,500. The number of new pairs found by Dr. AITKEN in the last biennial period is 265. . . .

During the biennial period Dr. AITKEN has secured 1,050 complete sets of micrometer measures of double stars. He has computed orbits for eight well-known double stars, whose periods of revolution are short. . . .

Valuable measures of 159 double stars made outside of assigned duties by Mr. C. P. OLIVIER, Carnegie Assistant, partly in this and partly in the preceding biennial period, were published in Bulletin 190.

Observations of the Struve double stars made by Professor HUSSEY in 1901-03, principally with the 12-inch telescope, which remained unpublished during the following decade, have been issued as Bulletin 206.

During the years 1910-11 Dr. AITKEN secured thirty-nine complete sets of measures of the four satellites of *Uranus,* each set comprising eight or ten micrometer measures of direction and eight or ten measures of distance. These observations, including Dr. AITKEN's former series, beginning with 1898, are now being utilized by Professor HERMANN STRUVE, director of the Royal Observatory, Berlin, as the basis for a complete discussion of the orbits of the four *Uranian* satellites. It is of interest to note that STRUVE's recent comprehensive orbital determinations for the two satellites of *Mars* are based upon Dr. AITKEN's micrometer measures with the 36-inch refractor, and upon a shorter series of similar observations secured by Professor BARNARD with the 40-inch refractor of the Yerkes Observatory.

Accurate observations of the positions of comets were made as follows: 5 observations by Dr. AITKEN; 24 observations by Mr. YOUNG, Fellow; 41 observations by Mr. KIESS, Fellow.

Micrometer determinations of the positions of asteroids were secured as follows: 18 observations by Mr. KIESS.

Accurate positions of asteroids were determined by means of photographs as follows: 16 observations by Dr. H. C. WILSON; 10 observations by Mr. KIESS.

Photographs of comets for use in studies of their structure and internal motions were secured as follows: 25 photographs of Comet *c* 1911 (BROOKS) by Dr. CURTIS with the Crossley reflector; 3 photographs of Comet *g* 1911 (BELJAWSKY), 3 photographs of Comet *b* 1911 (KIESS), and 12 photographs

of Comet *c* 1911 (BROOKS), by Mr. KIESS, with the Crocker telescope. Comet *b* 1911 was discovered by Mr. KIESS by means of a photograph which he had obtained in searching for Encke's comet.

The spectra of Comets *b* 1911 (KIESS), *c* 1911 (BROOKS), and *g* 1911 (BELJAWSKY) were observed by Astronomer WRIGHT. On account of the unusual intrinsic brilliancy of Comet *c* 1911 and the length of time it remained in positions favorable for observation, extremely valuable observations of its spectrum were secured. These have been published in Bulletin 209.

A preliminary orbit and later an improved orbit of Comet *c* 1911 (BROOKS) were computed by Mr. YOUNG, and published in Bulletins 200 and 202, respectively.

Elliptic elements for asteroid 1909 HZ were computed by Mr. Young, and published in Bulletin 191.

Elliptic elements for asteroid 1909 HC were computed by Mr. YOUNG and Dr. H. C. WILSON, and published in Bulletin 192.

In the past two years "new stars" have appeared in the constellations *Sagittarius, Lacerta,* and *Gemini.* Their spectra have been photographed and studied by Mr. WRIGHT. *Nova Sagittarii* was faint and unfavorably situated for observation, but results of considerable value were secured. The accurate position of *Nova Sagittarii* was fixed micrometrically by Mr. OLIVIER. The results for this star are contained in Bulletin 195.

Nova Lacertæ offered better conditions for observation, and the photographs recorded the spectrum from extreme red to ultra-violet. During the observation period the spectrum passed through the transformations usual in such cases, from the so-called "new star" spectrum to a spectrum consisting of broad bright bands occupying the positions of the nebular lines. The accurate position of *Nova Lacertæ* was determined from plates taken with the Crossley reflector by Dr. CURTIS. The results for this star are published in Bulletin 194.

The spectrum of *Nova Geminorum* is at present under investigation on the basis of a large number of photographic spectra secured by Mr. WRIGHT prior to June, 1912. During the last few weeks of its appearance Mr. WRIGHT noted the gradual

coming in of the bright bands which are characteristic of nebular spectra. Position observations of *Nova Geminorum* were secured with the meridian instrument by Mr. TUCKER, promptly following the announcement of discovery. . . .

Sixteen Crossley reflector photographs of novæ have been secured by Dr. CURTIS. Some of these, with long exposure times, were taken for the purpose of recording and detecting possible nebulous structure surrounding the novæ, such as was observed in the case of *Nova Persei.* Structure of this kind has not been observed in the vicinity of any of the recent novæ.

Dr. CURTIS obtained forty-four Crossley reflector photographs of the Ring Nebula in *Lyra* for the use of Dr. NEWKIRK, recently assistant in the Lick Observatory, in his investigations on the distance of the Ring Nebula. Of other Crossley photographs obtained by Dr. CURTIS we may refer to twenty-four plates exposed at the request of Harvard College Observatory, on certain definite regions of sky, for assistance in the Harvard determinations of standards for faint stellar magnitudes; and to thirty photographs of nebulæ and star clusters, mainly of objects not hitherto photographed.

Under Dr. CURTIS's supervision, Professor MOREHOUSE, of Drake University, and Mr. W. F. MEYER, of the Berkeley Astronomical Department, secured Crossley reflector photographs and positions of the three outer satellites of *Jupiter,* six of Satellite VI, seven of Satellite VII, and six of Satellite VIII. The results are ready for publication.

The Crossley reflector was used by Dr. KEIVIN BURNS, Carnegie Institution Assistant, during the year 1910-11, in extensive studies of the Great Nebula in *Orion,* and of the Ring Nebula in *Lyra.* The results for the latter were published in Bulletin 193.

Many of the photographs of the solar corona, obtained by Astronomer PERRINE on the occasions of recent Crocker eclipse expeditions, have been carefully studied by Mr. YOUNG. His results, forming a thesis in partial fulfillment of requirements for the degree of doctor of philosophy in the University of California (May, 1912), have established that the proportion of polarized light to unpolarized light in the corona varies with the angular distance from the edge of the Sun, but is

independent of the direction from the Sun's center. The observed polarization is much greater in the blue rays than in those of longer wave-lengths. Mr. YOUNG concludes that two thirds or more of the light of the corona is due to the scattering, by small coronal particles, of the light from the Sun which falls upon those particles.

As in preceding years, the most extensive investigations in progress at Mount Hamilton are based upon spectrographic determinations of stellar velocities, by means of the D. O. Mills spectrograph attached to the 36-inch refractor, and with the co-operation of the D. O. Mills Observatory on Cerro San Cristóbal, Santiago. The task of securing four or more spectrograms for every star down to the fifth visual magnitude, excluding those whose spectra do not contain lines measurable with fairly high dispersion, has been entirely completed at Mount Hamilton for the northern sky, and is in effect complete for the southern sky. In addition, several hundred spectrograms of stars fainter than the fifth visual magnitude have been secured at Mount Hamilton, and perhaps a thousand such spectrograms at Santiago. The numbers carried by the spectrograms obtained at Mount Hamilton during the biennial period extend from 6,530 up to about 7,925, though a few one-prism spectrograms secured are included. The spectrograms obtained from the beginning of observation at Santiago, in 1903, up to July 1, 1912, number about 4,400. All of the spectrograms, both north and south, have been measured and reduced definitively, excepting a few relating to spectroscopic binary stars whose investigations have not yet been commenced. The observations of the past two years on Mount Hamilton have been secured chiefly by Dr. H. C. WILSON, Messrs. OLIVIER, YOUNG, MERRILL and KIESS, Dr. R. E. WILSON, and Mr. SHEPPARD. All of these have taken part in measuring the spectrograms, but the most extensive measurements and reductions of the spectrograms have been made by Miss A. M. HOBE and Dr. KEIVIN BURNS, Carnegie Institution Assistants, and by Dr. H. C. WILSON and Dr. R. E. WILSON.

Extended studies of the systematic errors which affect the results for individual spectral lines have been made especially by Dr. BURNS.

A large number of southern spectrograms remaining unused at the beginning of the biennial period have been measured and reduced by Dr. CURTIS and Mr. OLIVIER.

My last report mentioned many interesting results as described in the Silliman lectures, which came from a discussion of the radial velocities of 1,060 stars and of thirteen nebulæ then available. A year later, in the early spring months of 1911, the available velocities of 1,193 objects formed the basis for more extended studies of stellar motions. Space is lacking for detailed presentation of results, but in general terms I shall state a few conclusions.

In preparing the Silliman lectures, I had found the algebraic mean velocity of 138 Class B stars to be $+ 4.93^{km}$ per second, whereas I had expected a value differing little from zero. A literal interpretation of this residual velocity would signify that the universe of Class B stars is expanding, with reference to the position of the solar system as a center, at the rate of 4.93^{km} per second; but I did not attach great weight to this interpretation. It was assumed as a more probable explanation that in the Class B stars the wave-lengths of the lines of the elements hydrogen, helium, oxygen, carbon, etc., differ from the laboratory determinations—perhaps owing to the existence of greater pressures in the atmospheres of the stars.

Professor KAPTEYN announced late in 1910 that the Class B stars in a large region of the southern sky are essentially all traveling along parallel lines with equal velocities, such that they are receding from the point of space occupied by the solar system at the rate of 5^{km} per second; and that the Class B stars in another great region of northern sky, exactly opposite to that referred to in the southern sky, are similarly traveling together along lines nearly parallel, with velocities nearly equal, such that they are receding from the point occupied by the solar system with a speed of about 5^{km} per second.

Believing that the speed 5^{km} per second assigned by KAPTEYN to the two groups of Class B stars corresponded exactly to the mean algebraic velocity $+ 4.93^{km}$ per second, which I had found a year earlier, I made a new investigation of the Class B velocities. The measured radial velocities of 225 stars were available. The discussion established beyond question that the

algebraic mean radial velocities of Class B stars are on the average about + 4.6^{km} per second, not only in the two KAPTEYN regions of the sky, but in all regions where the stars of this class are found. We were justified in calling this prevailingly positive residual velocity an unavoidable systematic error of observation. In all probability it is due to the prevalence of special conditions, such as high pressures, in the atmospheres of the Class B stars. After making due allowance for this systematic error, the motions of the two KAPTEYN groups of stars were found to possess the same characteristics as the groups of Class B stars in other regions.

The motion of the solar system was re-determined with reference to the 1,193 radial velocities. It was found that the solar system is moving with a speed of 19.5^{km} per second toward the point in the sky whose right ascension is 268°.5 and whose declination is + 25°.2.

The speed of the solar motion was also determined with reference to the stars in each of the principal spectral classes. . . . A few of the results are here given:—

Stars of spectral class.	No. of stars.	Velocity of solar motion.	Systematic errors.	Average radial velocities.
B	225	20.2^{km} per sec.	+ 4.1^{km} per sec.	6.5^{km} per sec
A	177	16.8 "	+ 0.95 "	10.95 "
F	185	15.8 "	+ 0.06 "	14.37 "
G	128	16.0 "	— 0.20 "	14.97 "
K	382	21.2 "	+ 2.82 "	16.8 "
M	73	22.6 "	+ 3.93 "	17.14 "

According to the generally accepted ideas of stellar evolution, the stars are supposed to have greater effective ages in the order of spectral classes B, A, F, G, K, and M. Our Sun is of Class G. We note that the velocity of the solar motion is smallest with reference to the systems of Class A, Class F and Class G stars. In brief, our Sun seems to partake of the motion of those stars that are of its own or slightly earlier effective age more than of the motions of the stars which are much younger and of stars which are older. . . .

KAPTEYN'S discovery that the stars have a preference for motion toward and away from two opposite points of the sky was confirmed by the 1911 discussion of our spectrographic

results, though the preferential motion was more strongly indicated by the 1909-10 discussion than by that of 1911.

It appeared from our later investigations that the preferential motion does not exist appreciably in the Class B stars. It is strongly indicated in the Class A stars and progressively less strongly in the stars of Classes F, G and K. It is doubtful if the effect exists in the brighter Class M stars.

It definitely appeared that the Class A stars not only have preferential motions in the KAPTEYN directions, but that their motions in general have a preference for small angles with the plane of the Milky Way. This conclusion has been confirmed upon the basis of our radial velocity data by Professor H. C. PLUMMER as a result of his valued study of the subject, in Bulletin 212.

Prior to 1910 it had been held that the bright stars of Classes B and A are on the average two and a quarter times as far away as the brighter stars of Classes F, G, K and M. Our spectrographic results as discussed in the Silliman lectures showed that this view was erroneous. The more extensive consideration of the subject in 1911 confirmed fully our conclusion that the brighter stars of Classes B and A are at the same average distance as the brighter stars of Classes F, G, K and M. However, a study of our radial velocity results by individual spectral classes, in connection with the proper motions assigned to the same stars in Professor Boss's *Preliminary General Catalogue* of star positions and proper motions, established beyond question that the bright stars of Classes F and G, which are those most nearly resembling our Sun in spectrum, are on the average much nearer than the stars of corresponding brightness in the earlier spectral Classes B and A and the later spectral Classes K and M. This result had been established previously for Class G stars. Our results seem to permit us to say that the bright stars are the nearer to our Sun the more nearly they approach the F and G spectral classes, and conversely the more distant from our Sun the more their spectra diverge from the F and G spectral classes. Professor Boss's simultaneous and independent discussion of the same subject, based upon proper-motion data, leads to substantially the same results.

Our recent studies have confirmed the result announced in

the Silliman lectures that the scale on which the universe of brighter stars is constructed is a great deal larger than we had previously supposed.

The discovery that the average velocities of the stars are functions of their spectral classes, increasing with advancing effective ages, made in January, 1910, and announced in the Silliman lectures, is abundantly confirmed by our later investigations, as shown in the last column of the table on page 247.

Perhaps the most interesting and important by-product of the spectrographic researches referred to is the discovery of systems of close double stars known as spectroscopic binaries. The proportion of observed binaries amongst the stars whose radial velocities have been observed is increasing with the lapse of time. The explanation of the increase is a simple one: The component stars in spectroscopic binaries of the older spectral classes are more widely separated than is the case amongst binaries of the early spectral classes. The periods of revolution in the older systems are longer and the variations of radial velocity are smaller and slower. The discovery of these variations requires that the observations cover longer periods of time. By virtue of the observations secured by the D. O. Mills spectrograph at Mount Hamilton, by the D. O. Mills Observatory at Santiago, and by the Bruce spectrograph of the Yerkes Observatory on the stars of Classes B and A, we may say that one star in four, on the average, of all the stars down to the fifth visual magnitude, is a double star whose component stars are so close together that the most powerful telescopes are unable to separate them. With the progress of time, as stated above, the ratio has increased, and I think we may be able to say in another decade that at least one star in every three is a spectroscopic binary system; and I should be surprised if the observations of the twentieth century do not establish that one star in every two and a half, on the average, is composed of two or more suns revolving about their mutual center of mass. These systems are not sporadic cases in the domain of sidereal evolution; they must in fact be the results of general or widely prevailing tendencies in stellar life.

The high efficiency of the D. O. Mills Expedition has been

fully maintained by the devotion of Dr. JOSEPH H. MOORE, acting astronomer in charge, and of those who have been associated with him. Mr. GEORGE F. PADDOCK left the employ of the expedition at the conclusion of five very satisfactory years of service, in July, 1911. He was succeeded by Mr. ROSCOE F. SANFORD, formerly Carnegie Institution Assistant at Mount Hamilton. The majority of the spectrograms have been measured and reduced by Mrs. JOSEPH H. MOORE. Dr. PADDOCK has been appointed assistant in the Lick Observatory for the academic year 1912-13.

The orbit of the spectroscopic binary *ζ Serpentis* has been determined from twenty-seven plates obtained with the D. O. Mills spectrograph, by Mr. YOUNG, and published in Bulletin 203.

Mr. MERRILL computed the orbit of the spectroscopic binary *β Capricorni* from forty-five observations made with the D. O. Mills spectrograph. The results are published in Bulletin 178.

Mr. MERRILL has secured more than one hundred spectrograms of stars whose spectra contain bright lines, as a partial basis for a thesis looking toward the degree of Doctor of Philosophy.

Mr. KIESS has obtained thirty-one spectrograms of RR *Lyræ*, an especially interesting variable star, as a partial basis for a thesis looking toward the degree of Doctor of Philosophy.

An interesting study of the spectrum of P *Cygni*, an especially interesting bright-line star, made by Mr. MERRILL, is published in Bulletin 201. . . .

The director acknowledges with pleasure the support which he has received from every member of the staff, and desires especially to thank those of the D. O. Mills Observatory at Santiago, Chile, and those of his colleagues at Mount Hamilton who have assisted in securing and measuring stellar spectrograms and in making calculations relating to the motions of the stars.

Respectfully submitted,

W. W. CAMPBELL,

Director of the Lick Observatory.